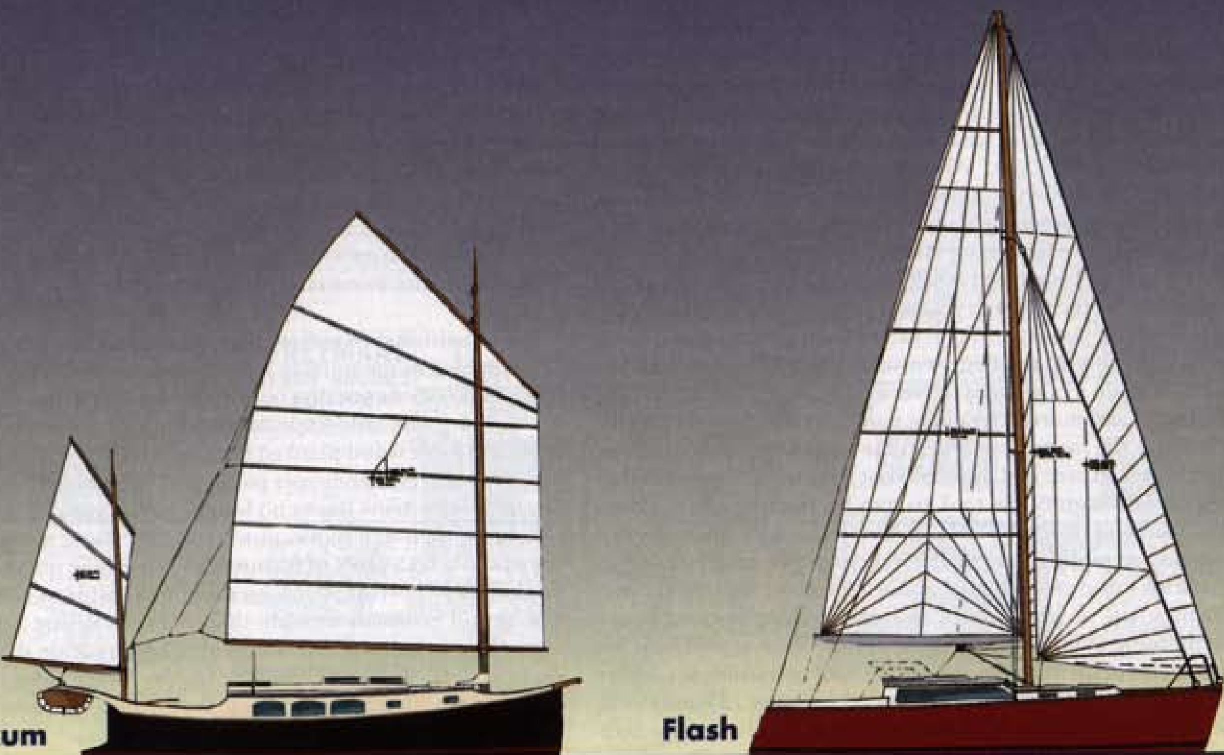
Sailing Cruiser Design



History, hydrostatics, and art, PART 2

What are the factors a naval architect considers when designing a cruising sailboat? In Part 1 of this series, Tad Roberts began a discussion of how the interrelationship of hull form, waterline length, displacement, and sail area affects a sailboat's performance and suitability for a particular purpose. He illustrated that article with four small cruisers of his own design: Captain Flint, a 17′ camp-cruising cat-ketch for protected waters; Ratty, a 20′ light-displacement cat-ketch; Teazer, a 28′ fin-keeled coastwise cruising ketch; and Hero, a 29′6″ offshore cutter. In this final installment of the series, Roberts examines four of his longer designs: a modern version of a traditional barge yacht; a high-performance coastal cruiser; and a pair of ocean voyagers. —Ed

Tilikum
A 32′ Centerboard Barge

Barge yachts have been around a long time, probably as long as yachting. Originating in Holland and then developing on the East Coast of England, they have great appeal to those of us who sail in creeks and backwaters. Reading Arthur Ransome and Maurice Griffiths, we are caught up in the idea of sailing up some uncharted and unnamed backwater to rest on the mud and watch all the water go away with the tide. To do this you need a boat with a flat bottom, and if it's a sailing boat you must have a lifting keel of some sort. To make this flat-bottomed vessel seaworthy and able one can add a raised deck, and we must pull out her ends to ease the entry and exit around that chunky midsection. Tilikum's form is much influenced by the work of designer Phil Bolger (see WB Nos. 157 and 164).

The barge yachts of Europe were commonly equipped with leeboards to meet the movable keel requirement. Leeboards are very efficient, but they are noisy and awkward. On the other hand, they don't clutter up the interior. Tilikum would be an ideal leeboarder with her long, flat sides. However, I have chosen to set her up with tandem centerboards, which have advantages and vices

Text and drawings by Tad Roberts

of their own. They are expensive, with two centerboard trunks and boards to build, and like leeboards they are noisy. For Tilikum I specify fiberglass construction for both boards and trunks. If you put the boat on the mud much, you will have problems with debris lodging between the boards and their trunks, so the trunks need to be large and the boards loose. I would build the trunks so you could easily uncap them to clean the mud out or jam something in there to stop the rattling. In Tilikum, the after trunk makes an ideal cockpit drain.

As any vessel moves through the water when sailing to windward, it makes leeway. Water flows from the lee high-pressure side to the weather low-pressure side. Because this flow bends around the hull, the after centerboard or rudder should have an increased angle of incidence over that of the forward or main keel. Otherwise, the after board is merely acting as a brake.

A number of designers have used tandem centerboards to good effect. Phil Rhodes, Sparkman & Stephens, Maclear & Harris, and Spaulding Dunbar have all created tandem-centerboard yachts that are considered exceptionally well behaved under sail. I assume owners of these vessels do not need to use their after boards when sailing to windward. The idea is to be able to balance, by raising or lowering either board, the underwater profile of the vessel to match the sail's set and point of sail. Pointing and close-reaching, the forward board is down and the aft one up. Running, the forward board is up and the after one is down. Broad-reaching, you adjust them until she sails herself, but remember to pull one up when you want to change course.

Tilikum is a coastwise light-displacement cruiser. Floating on her design waterline, displacement will be 12,000 lbs. This gives a displacement/length ratio of 168.

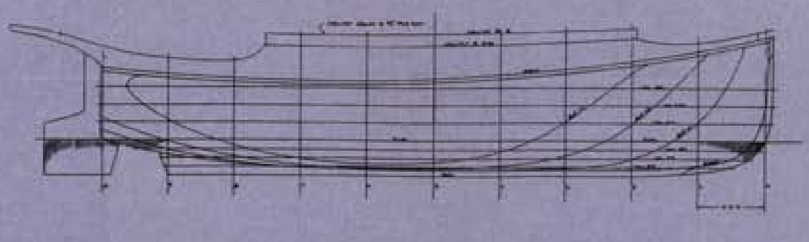
D/L is calculated as follows:

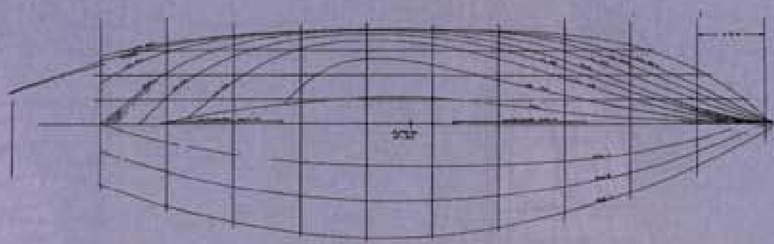
$$\text{Displacement/ Length Ratio} = \frac{\dfrac{\text{Displacement (lbs)}}{2240 \text{ lbs./ton}}}{(0.01 \times \text{DWL})^3}$$

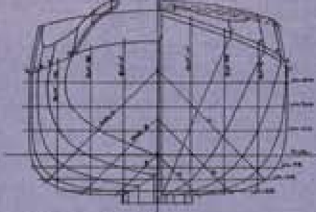
Three boats in our group have similar D/L: Teazer, the 28′ coastwise cruising ketch we discussed in Part 1 of this series; Tilikum; and the next boat, Flash.

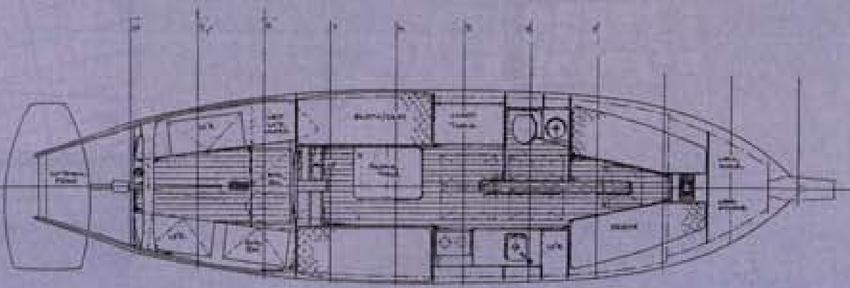
Particulars

LOA	32′0″
LWL	31′8″
Beam	9′0″
Draft (boards up)	1′8″
Sail area	615 sq ft total
Mainsail	528 sq ft
Mizzen	87 sq ft
Displ.	12,000 lbs
Ballast	4,200 lbs









Tilikum—This 32′ tandem-centerboard barge yacht will be much at home as she rests in thin water near the head of an uncharted creek.

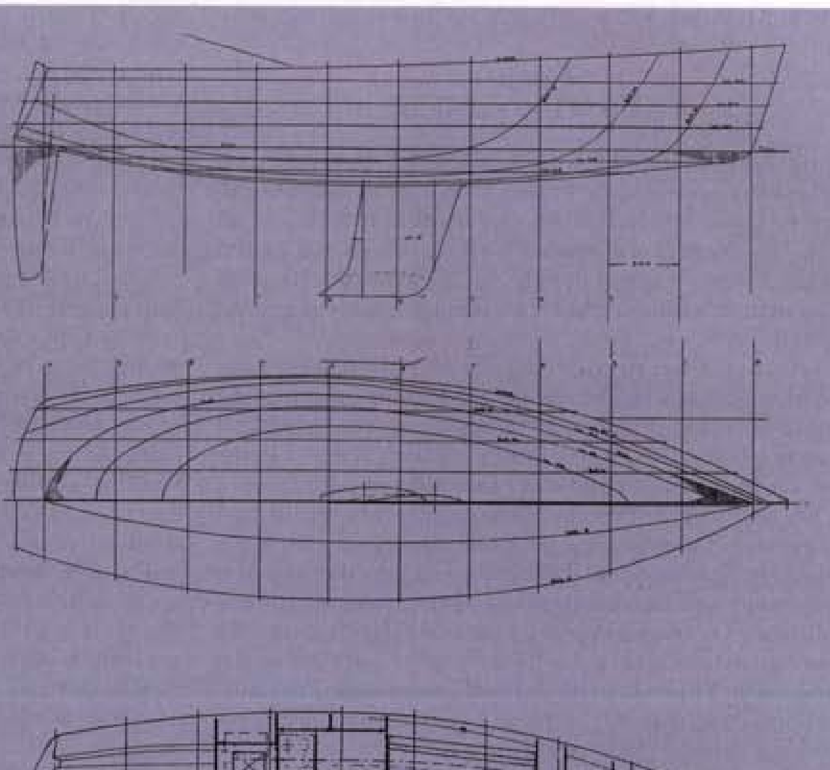
Twenty years ago, these designs would have been thought far too light and structurally weak to be cruising boats. With today's engineering and construction methods, they can be built strong enough to venture into the ocean. Though their D/Ls are similar, each has a very different hull form. What D/L tells us about hull form is that if the D/L is fairly low, the boat will have little underwater volume. This means a sacrifice in tankage and storage. So these three boats are meant to cruise alongshore where supply stops can be frequent.

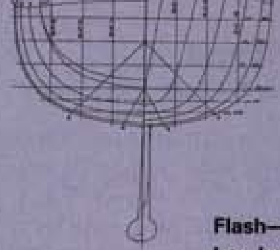
Another feature that Teazer, Tilikum, and Flash share is construction method. I have specified hull planking consisting of a cedar-strip core covered with fiberglass. In my view, the longitudinal strips are the best way to start planking one-off round-bottomed wooden boats. Planked upside-down on simple molds, the hull goes together quickly; and this is structurally the best way to handle the longitudinal bending loads induced by the rig. In the case of Teazer and Tilikum, the 'glass would be only on the outside, in a fairly heavy layup—say, two layers of 10-oz fiberglass. Inside would then be a beautiful, bright-finished cedar ceiling. For Flash, the racier vessel, I specify a lighter 'glass layup, inside and out of a slightly thicker core for a stiffer panel with slightly lower weight. An alternative to the fiberglass layup would be double- diagonal layers of ⅛″ cedar outside the longitudinal strips for an extremely rigid structure, but one requiring many more construction hours.

Tilikum's total displacement is 12,000 lbs, of which 4,200 lbs is ballast and 6,000 lbs is in the rig, structure, interior, and machinery. We have only 1,800 lbs left for outfit, crew, and stores. Is this enough? Probably not. With a small family as crew, and stores for a week-long cruise in Chesapeake Bay, Tilikum will be down on her lines at first. But it will take slightly more than 1,000 lbs to put her down an inch, and she can easily handle that. Why not build the boat slightly larger to support another 1,000 lbs of payload? To do that she would have to be physically larger: longer, deeper, or wider. That means more construction material, more construction hours,

Particulars

LOA	34′6″
LWL	31′8″
Beam	11′0″
Draft	6′6″
Sail area	661 sq ft total
Mainsail	324 sq ft
Foresail	337 sq ft
Displ.	11,500 lbs
Ballast	4,500 lbs





Flash—This 34′6″ fin-keeled sloop should sail fast, but she'll demand close attention to show her best.

and higher loads all around, requiring heavier, more expensive equipment. So I designed Tilikum for what I think will be her average sailing conditions, and included safety factors for anticipated overloads.

We notice two things right off when looking at Tilikum's profile. First is the unusual Chinese balance lug rig. There are several really good reasons to rig Tilikum in this way. First is ease of construction; it is low-tech, and it is possible to build the rig out of "found" parts. Ease of handling is its next great advantage. With a seeming spiderweb of lines, sheet and sheetlets, lazyjacks, and parrels, it looks complex. But in operation the lug rig is very simple; because of the balance, sheet loads are small. The heavy yard means that if you let go the halyard, the sail drops and settles neatly into its lazyjacks, no matter your course, the wind strength, or the strength of the crew. Controls are all led to the cockpit. This makes her an ideal vessel for the singlehander, with sail controls and tiller at hand under the semi-permanent cockpit awning.

In Tilikum's case the sailarea/displacement ratio is 17.1, and the vast majority of her sail area is the main, which will provide the drive. [SA/D = Sail area (ft^2)/ Displacement$(ft^3)^{2/3}$] This sail can be large because it is so easy to handle. The little mizzen is for balance, steering, and holding the ship into the wind at anchor.

Because there is no need to be running up to the mast, Tilikum can have a raised deck forward of the cockpit. This provides a wonderfully spacious interior, even though the vessel is of only moderate beam. It also provides tremendous reserve buoyancy up high; she will pop right back from a knockdown. Her moderate beam and high deck mean she will stay afloat on her side because the centerline hatches will be clear of the water.

Tilikum is aimed at a certain type of performance—the ability to sail coastwise in open water, yet also creep up tiny creeks to wait out tides while resting on the mud. With Flash we look at a totally different type of performance, that of the straight-line hot-rod. Again we discuss waterline length and its relationship to form. Then we look at how hull form works with the rig and appendages to achieve speed. We will also have a look at the ultimate stability question.

Flash
A 34′6″ Fin-keel Sloop

Of light displacement, with a tall rig and pared-down underwater appendages, Flash will require constant attention to sail at her best. With her rounded sections and deep, narrow keel and rudder, we have minimized wetted surface for good speed in light air. Wide beam with powerful quarters will give her the stability to get up and go when it blows.

Looking at her profile, we note very short overhangs and the almost straight sheerline. Maximum waterline length was the objective in this styling, though I still couldn't bring myself to cut her off with vertical ends. The short overhangs make her look like a boat.

Through the 1960s and '70s, sailing yacht hulls had longer overhangs and larger keels. As higher-efficiency foils were developed and keel size was pared down, volume was moved into a longer-waterline, higher-prismatic hullform. Open-class racing boats of the '80s and '90s have taught designers the benefits of maximum waterline length. Thus we arrive at Flash's long-waterline, tiny-keel-and-rudder form: an ideal mix (with what we know now) for speed in light and heavy air.

As I mentioned in Part 1 in the discussion of Captain Flint (a 17′ cat-schooner), wetted surface increases rapidly with waterline length but not as quickly with increased weight. At a given displacement, the longer waterline means more wetted surface. If you sail in light air, wetted surface is the major part of your boat's resistance. If you sail where there's lots of wind, the problem will be wavemaking resistance, which is minimized by a longer waterline.

Flash carries a tall rig; SA/D ratio is 20.76 at her design weight of 11,500 lbs. I considered three different rigs for this boat. The BOC type with masthead foretriangle, huge roach in the main, and no standing backstay, lacks durability. A ¾-sized foretriangle with jumpers and standing backstay is too finicky. My final choice was the masthead rig with standing backstay. In heavier winds the genoa is rolled up and the main reefed. With running backstays opposing the inner forestay, you can carry on under a well-stayed, short, and balanced sail plan.

In my view Flash is not an offshore or ocean cruising yacht. She does not have the dynamic or ultimate stability to qualify as an "Unrestricted Offshore" class of vessel. We talked in the Teazer description about Dellenbaugh angles, but that alone is not an index of seaworthiness. The measurement of dynamic stability is much more complex: the STIX standard.

Much research has been done into the reasons and mechanics of small-yacht capsize. One of the key factors is boat size. A larger boat is less likely to capsize because its larger mass is more resistant to movement by waves. Relatively speaking, the larger the boat, the smaller the waves. For a boat of Flash's size, the unrestricted ocean sailing requirement is positive stability to about 140°. The current ISO (International Organization for Standardization) 12217–2 Small Craft Stability and Buoyancy Standard includes a "Stability Index"(STIX). This is a factor based on the length, beam, displacement, and righting moment curve of the vessel. With positive stability only to about 125°, Flash will meet EU (European Union) requirements for operation up to 20 miles from a safe haven. Flash has a STIX of 30.5, and this puts her in Design Category B, Offshore, for use in winds of up to Force 8 Beaufort, (34–40 knots) and wave heights up to and including 13′. In Flash I would definitely seek shelter before being caught in these conditions! [For more information on STIX, see *Principles of Yacht Design* (Second edition, International Marine, 2000) by Lars Larsson and Rolf Eliasson.]

The appendages on Flash are deep and narrow. In testing, it has been found that deep, narrow foils are more efficient than shallow, wide ones. Efficiency is determined by measuring lift versus drag, or the resisting side force from the rig versus opposing resistance created by the keel and rudder. The problem with deep, narrow foils is that they "stall," or quit working at smaller angles than a shallower longer foil. Concentration at the helm is required to keep Flash "in the groove" and sailing at her best. To my way of thinking, this is not relaxing. But, if the boat is well sailed, the deep, narrow foils provide maximum lift for a given wetted surface.

Where Flash is extreme, let us now consider a more moderate version of that same type, the high-performance voyager. Wizard is larger, heavier, with proportionately less sail area, and so will be more comfortable, forgiving, and easier to handle than Flash. He is also of a more timeless style. Let's see how that goes with his performance objective.

Wizard
A 39′ Fin-keeled Ocean Cruiser

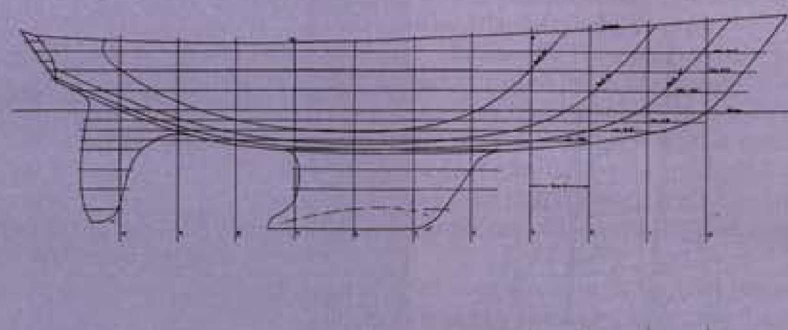
Wizard is a much larger boat than Flash. Though only 4′6″ longer, he weighs more than half again as much. At 18,500 lbs displacement, his D/L is 305. Ten years ago this would have been considered moderate for a cruiser. Today he is in the bottom of the heavy range. Part of this is due to the long overhangs. If I had included the fairing over the rudder, his DWL would be 31′7″, for a D/L of 262. That's right in the middle of moderate. (The larger number gives an indication of his at-rest hullform, while the second number is indicative of her sailing hullform.)

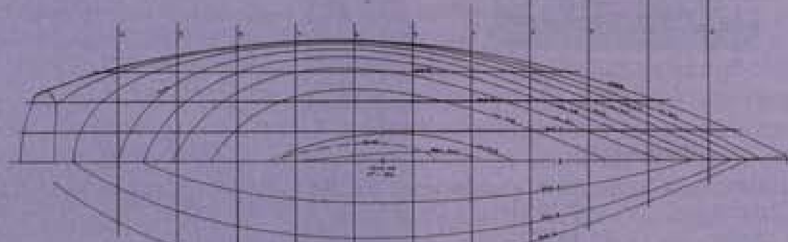
Wizard is large enough for three or four people to live aboard for long periods, and has the hull volume to carry the stores necessary for a long voyage. His weight will increase substantially at the start of such a voyage. With their gear and provisions, each person aboard means another 1,000 lbs, minimum. With three people aboard and prepared to set off on a long cruise, the extra 3,000 lbs will put him down 2.3″, a small amount in the overall scheme of things; he could handle twice that. At a weight of 21,500 lbs, the longer waterline will give him a D/L of 304. Certainly we need a pretty good idea of the load condition before making assumptions about a vessel from its D/L ratio.

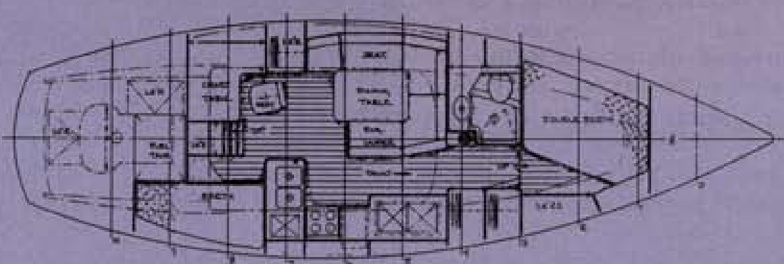
In hull form, Wizard is what I call a modern classic. His overhangs are not as long as those boats featured 40 years ago, but they are still long enough to draw out the lines gracefully. His sections are well rounded in the topsides and become veed in the bottom. As a modern design, the freeboard is much higher than older designs, so the

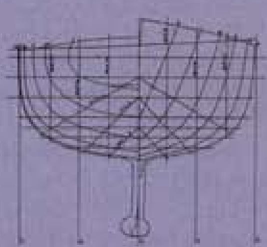
Particulars

LOA	39′0″
LWL	30′0″
Beam	12′2″
Draft	6′0″
Sail area	724 sq ft total
Mainsail	337 sq ft
Foresail	387 sq ft
Displ.	18,500 lbs
Ballast	8,000 lbs









Wizard—This 39′ fin-keeled ocean cruiser, will carry a crew of three or four sailors just about anywhere they might care to go.

rounded sections are important amidships, where straighter sections make hulls look slab-sided. This roundness is also important aft; again, this is a modern design so the quarters are fuller (beamier) than earlier designs. The fuller quarters mean he picks up power (stability) as he heels. If this is carried too far, the boat trims down by the bow as he heels—a major contributor to balance instability and steering problems.

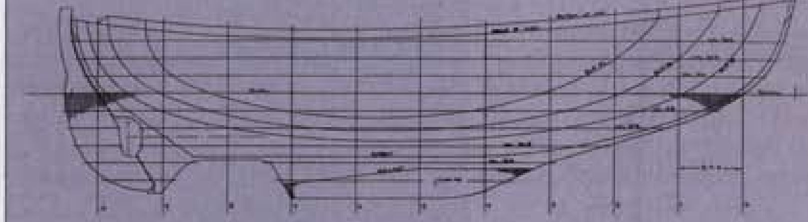
I can get away with this increased beam visually by disguising it behind lots of curved surfaces. As I mentioned in my discussion of Hero in Part 1, the modern fin keel underbody pushes the cabin sole up, and this is what drives the freeboard up. To visually balance the hull mass against that of the cabin trunk is the next trick. To me, low cabin sides and higher freeboard always look better. Bulwarks will help to visually minimize cabin height, and they are certainly proper on a boat such as Wizard.

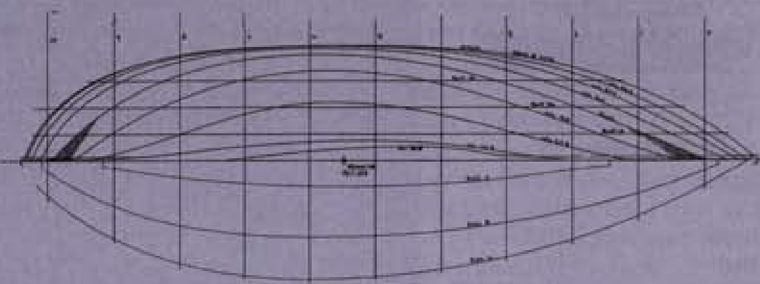
The modern classic designation also means a moderate length fin keel and separate skeg rudder. This configuration is another compromise between directional control and wetted surface. The keel also must be big enough to contain the ballast, and if it's fairly long this is not a problem. Wizard's fin has a bulb at the bottom to lower the ballast CG, therefore the fin is longer on the bottom than on the top. The partial skeg is there for two reasons. The first is support. A lower rudder bearing at the bottom of the skeg, about halfway down the rudder, will minimize the chance of the rudder being bent over and jammed catastrophically. The second reason is hydrodynamic. Water flow will remain "attached" longer on the rudder with a fixed skeg in front of it; thus the rudder will be more forgiving and the vessel easier to keep under control.

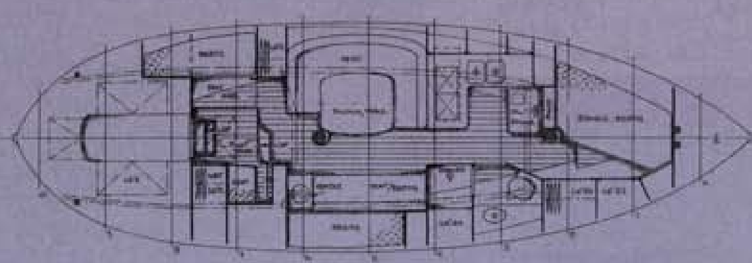
The deckhouse is inspired by a couple of pictures of John Alden's Challenger design, from Arthur Beiser's book *The Proper Yacht* (Macmillan, 1966). Big, fixed windows can transform the main cabin of a sailing yacht into an airy, light-filled space. (For structural integrity, this glass area is divided into three smaller sections.) Part of my definition of modern classic is the elimination of

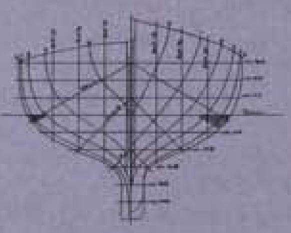
Particulars

LOA	42'0"
LWL	37'6"
Beam	13'0"
Draft	6'0"
Sail area	1,044 sq ft total
Mainsail	418 sq ft
Foresail	313 sq ft
100% Foretriangle	310 sq ft
Displ.	33,000 lbs
Ballast	11,500 lbs









Wild Cat—Construction of this schooner might consume 9,000 hours, but the 42' double-ender should prove world-capable and fast for its type.

dark, cramped accommodations.

The low cabin trunk forward will provide 6'0" headroom and space for hard-dinghy stowage on deck. The cockpit is roomy enough for three or four people. However, it is split by the mainsheet traveler. If the cabin were longer, the traveler could go up forward of the main hatch. But with this length of cockpit, the forward position would take too much sheeting force, so I compromised with an option that puts the traveler closer to hand.

Again we have the tall, masthead cutter rig with running backstays opposing the inner forestay. Readers may think I lack imagination when three out of the eight designs discussed in this series are masthead cutters. But, historically and pragmatically, I think the masthead cutter is what is expected in this type of boat. We could make Wizard a ketch, but this would add complication, expense, weight, and clutter the cockpit. We could rig him as a lug schooner, but that rig doesn't match the performance expectation implicit in his underbody. With modern sailing gear, powerful winches, low-friction blocks, high-strength line, etc., handling the cutter rig is entirely within the capabilities of two experienced and reasonably active crew. Of course, there is a price. Failure of any one of hundreds of individual, expensive, factory-made pieces could bring the rig down, and that's something to consider when sailing offshore.

And so we leave the cutter and come to our last boat, Wild Cat, a schooner. His displacement/length ratio is 280, similar to that of Wizard. But Wild Cat's waterplane is much larger than that of the smaller boat. He will be less affected by the overload of stores and equipment needed for a long cruise. Let's look at how this hull form can be shaped for best performance—given that he is not a high-performance type.

Wild Cat
A 42′ Double-ended Schooner

Wild Cat is a big boat, 2.5 times longer than our other schooner, Captain Flint. But he displaces more than 15 times as much! We said Captain Flint would take about 400 hours to build, so you can figure on Wild Cat taking at least 15 times that, or 6,000 hours. That would be for the basic boat—add another 3,000 hours for furniture and systems.

Heavy, beamy double-enders have been the epitome of cruising boats for many years. In the 1930s, '40s, and '50s they were considered by many to be the only boats suitable for offshore cruising. Certainly, features drawn from Colin Archer rescue vessels are good for ocean voyaging: heavy displacement, voluminous interior space, and seaworthiness. But rescue ships are not cruising yachts, and so they must be modified to improve handling, speed, motion, and to take advantage of modern construction methods.

Yacht designer Aage Nielsen started modifying the traditional Colin Archer type in the 1930s (see WB No. 133). His HOLGER DANSKE of 1964 is near in size to Wild Cat. At 42′6″ LOA, HOLGER DANSKE has 13′3″ of beam for a beam-to-kength ratio of 0.31. I decided on a B/L of 0.30 for Wild Cat, so his beam comes out at an even 13′0′. Wild Cat is close to HOLGER DANSKE in some other particulars such as displacement, but Wild Cat will carry more ballast on account of his lighter cold-molded structure.

Is the double-ender more seaworthy than other hull forms? I don't believe so, but a double-ended boat can be as seaworthy as any other type. Colin Archer designs have a beautifully rugged shape but are too fine aft to damp out pitching caused by their full forward sections. These boats have a reputation for being able to sail off a lee shore in some terrible seas. This is mostly due to their tremendous mass, which gives them the momentum to butt through rough seas. Their beamy hulls also allow them to stand up to their sails in heavy weather.

Drawing Wild Cat's lines, with their wonderful symmetry, was a pure pleasure, and it's easy to see how these boats come to captivate people. If I retained Colin Archer's beam/length proportions for Wild Cat, he would come out about 14′3″ wide. This would create a nice, roomy interior, but the waterlines are too full forward, meaning he would be too blunt for good windward performance. Looking at half-angles of entry is an easy way to measure how blunt or fine the bow of a boat is. Measuring the angle between the centerline and waterline at the stem of a Colin Archer rescue vessel gives a result close to 30°. Modern cruisers run somewhere between 18° and 22°; racers are much finer. Wild Cat came out at 22°.

Wild Cat is finer forward and fuller aft, at both the deck and waterline, than a traditional Colin Archer design, so the buttock lines have some run to them before they turn up aft. His sections are also flatter aft, making him less V-shaped—again to maximize damping. The seagoing comfort of a particular vessel will lie in its motion, how fast it will roll or pitch. Fast is uncomfortable, slower is better. As we have discussed, motion is dependent on displacement and waterplane area.

Designer Ted Brewer distilled these factors into a motion comfort ratio: Displacement in pounds/(0.65 × (0.7 LWL + 0.3 LOA) × Beam$^{1.333}$. The numbers, essentially the boat's displacement divided by its size, range from 5.4 for a Lightning (not very comfortable) to a very comfortable 74 for NINA, a 59′ schooner. Wild Cat comes in at 42.75, a good medium and close to the well-known Sparkman & Stephens yawl FINISTERRE. The Colin Archer rescue vessel is about 66, an indication of good comfort in a seaway.

I have drawn Wild Cat with a slight fin keel below traditional wineglass sections. This is an attempt to improve windward performance while retaining the better facets, as discussed in Hero, of the deeper sections.

So we come to his rig. I like schooners, and that rig is a bit unusual on this type of hull, so it's interesting to look at. The schooner rig splits the sail area into four pieces, which can be set in a number of combinations. No one sail is very large, and sheets and halyards can be handled with tackles or small winches. With this versatility, one can achieve balance between hull and rig on any point of sail and in all wind strengths. That's the main beauty of the rig. The drawbacks are increases in windage, weight, and expense. But the schooner has so much deep-sea character, I find it hard to resist.

Looking at Wild Cat's profile, a couple things are of note. The first is his sheerline, the curvature of which increases rapidly toward his ends. Why would I do this? We need to remember that all these lines are three-dimensional in the real world. Looking at Wild Cat's deck plan, we again see sharp curves at each end, with a flatter line between them amidships. Looking at the boat's profile, the sheer is bending away from your eye so quickly that it becomes visually flat. So, the sheer of every boat becomes flatter in three-dimensions than it appears to be in a two-dimensional drawing. That is why sheerlines, especially near the bow and stern, must be finalized with a batten on the boat as it's being built, the traditional method—or you might get close with a three-dimensional computer model.

Also of note is the small pilothouse forward of the cockpit. It is difficult to get this structure into the proper scale for the boat. Originally I drew it much larger. I kept erasing and redrawing until, standing a long way back and squinting, it didn't stick out like a sore thumb. It is small, but will be so much better than no pilothouse at all.

I think Wild Cat turned out well. In fact, I think the whole fleet turned out well. Waterline length and displacement informed almost every design decision, and I hope that this discussion has shed some light on how these factors affect form, performance, motion, and use in boats of different design. It is the addition of art and romance that makes small cruising yachts endlessly fascinating and appealing.

Tad Roberts grew up in British Columbia close to the water and boats. After 15 years spent designing megayachts in Maine, he returned to his home waters and opened a new design office. In his spare time, he serves as a director for the Silva Bay Shipyard School and sails RATTY, his 20′ cat-ketch. You can reach him at P.O. Box 33, Gabriola Island, BC, V0R 1X0, Canada.